# MINERAL NUTRITION

Date / /
Page

* Basic needs of All living organisms are essentially same.

they require → MACROMOLECULES → Carbohydrates, protein, Fats, minerals, water → For growth, • Development

## → METHODS TO STUDY THE MINERAL REQUIREMENTS OF PLANTS?

* In 1860, Julius Von Sachs (prominent German Botanist) demonstrated for 1st time

HYDROPONICS: Plants could be grown to maturity in Defined nutrient solution (in complete absence of — soil)

* The essence of all these methods involves → culture of plant → in soil-free, → Defined mineral soln.

methods require → mineral nutrient salts, purified water

Hydroponics has been successfully employed as → technique for → Commercial production for vegetables → Seedless cucumber, Tomato, Lettuce

* Nutrient soln must be → adequately aerated to obtain → optimum growth.

## → ESSENTIAL MINERAL ELEMENTS

* Most of the minerals present in soil can enter plants through → Roots
* >60 of 105 discovered are found in → different plants
* Some plant species accumulate → Se (selenium)
  - some other → Au (gold)
  - growing near nuclear test site → Radioactive Sr (strontium)
* There are techniques that are able to detect → minerals even at → low. conc. ($10^{-8}$ g/mL)



## → CRITERIA FOR ESSENTIALITY

| ① Element must be | ② Requirement of element | ③ Element must be |
|---|---|---|
| absolutely necessary for supporting → normal growth, Reproduction<br>In absence of element → plants do not complete life cycle or set the seeds. | must be specific & not replaceable by another element.<br>Deficiency of any one element cannot be met by supplying some other element. | directly involved in metabolism of plant. |

Based on above criteria → only a few elements have been found to be absolutely necessary for normal growth & metabolism

based on quantitative req.

Macronutrients | Micronutrients

**Macronutrients** → generally present in → plant tissues (in large amts — in excess of 10 mmole $kg^{-1}$ of dry matter)

C H O N P S K Ca Mg

C, H, O — mainly obtained by → $CO_2$, $H_2O$

N P S K Ca Mg — mainly absorbed from → soils as mineral nutrition



**Micronutrients** or → trace elements (less than < 10 mmole $kg^{-1}$ of dry matter)

Include

Fe, Mn (manganese), Cu, Mo, Zn, B, Cl, Ni

- In addition to above 17 elements, there are few BENEFICIAL ELEMENTS such as → Na, Si, Co, Selenium
  - They are req. by higher plants.

Na se Si Co

→ Essential Elements can be grouped in 4 broad categories on basis of : diverse Function

① Essential elements as components of biomolecules — hence Structural elements of cells
C H O N

② Essential elements as → components of energy related chemical compounds in plants
Mg → in chlorophyll
P → in ATP

③ Essential elements that → activate / inhibit enzymes
$Mg^{2+}$ → activator for → RuBisCo, PEPCo — essential enzymes for photosynthetic Carbon fixation
$Zn^{2+}$ → activator of → Alcohol Dehydrogenase
Mo → activator → Nitrogenase (for $N_2$ metabolism)

④ Some elements can alter osmotic potential of a cell.
K → helps in closing / opening of stomata.

# Role of Macro & Micro-nutrients

* Essential elements → perform → various metabolic processes in plant cells
  - permeability of cell membrane
  - maintenance of osmotic conc of cell sap
  - ETS
  - Buffering action
  - Enzymatic activity
  - Major constituents of → macromolecules, → co-enzymes

## 1. NITROGEN

- req by plants → in greatest amount
- absorbed as → $NO_3^-$ (mainly)
  - in some as → $NO_2^-$, $NH_4^+$
- req. by all parts of a plant, particularly
  - Meristematic tissues
  - metabolically active cells
- major constituent of
  - Proteins
  - nucleic acid
  - vitamins
  - hormones

## 2. PHOSPHOROUS

- absorbed from soil as → phosphate ions → $H_2PO_4^-$, $HPO_4^{2-}$
- constituents of
  - cell membranes
  - certain protein
  - All nucleic acid
  - nucleotides
- req for all phosphorylation rxns

## 3. POTTASSIUM

- absorbed as → $K^+$ ion
- req in more abundant quant. in
  - meristematic tissues
  - buds
  - leaves
  - Root tips
- Opening & closing of stomata
- maintain anion - cation balance.
- protein synthesis
- Activation of enzymes
- maintenance of turgidity of cells

## 4. CALCIUM

- absorbed from soil → $Ca^{2+}$
- req. by
  - meristematic tissues
  - differentiating tissues
- form of → mitotic spindle
- used during cell division for formation of → cell wall → as → Ca pectate in the middle lamalle.
- accumulates in → older leaves.
- involved in → normal functioning of cell membrane
- activates → certain enzymes
- regulate → metabolic activity.

## 5. MAGNESIUM

- obtained as → $Mg^{2+}$
- activates enzyme for
  - photosynthesis
  - respiration
- used in synthesis of
  - DNA
  - RNA
- helps maint aining ribosome structure
- constituent of ring structure of chlorophyll

**(6) SULPHUR**

- obtained in form of → $SO_4^{2-}$
- present in 2 AA → cysteine, methionine
- main constituents of → Coenzymes → Coenzyme A; Vitamins → Thiamine, Biotin; Ferredoxin

**(7) IRON**

- obtain in form of → $Fe^{3+}$ (ferric ions)
- req. in → larger amounts in comparision to other micronutrients
- imp constituents of proteins involved in → transfer of $e^-$ like → Ferredoxin, Cytochromes
- activates → Catalase enzyme
- essential for form. of → Chlorophyll.
- reversibly oxidized from → $Fe^{2+} \rightarrow Fe^{3+}$ (during $e^-$ transfer)

**(8) MANGANESE**

- absorbed in form of → $Mn^{2+}$ (manganous ions)
- activates enzyme for → photosynthesis, respiration, Nitrogen metabolism — Mn
- best defined function → Splitting of water to liberate $O_2$ during photosynthesis

**(9) ZINC**

- plants obtain it as → $Zn^{2+}$ ions
- activates various enzyme → carboxylases especially
- used for synth esis of Auxin

**(10) COPPER**

- absorbed as → $Cu^{2+}$ (cupric ions)
- essential for → overall plant metabolism
- its associated with certain enzymes involved in Redox Rkns → Reversibly Oxidized $Cu^{+} \rightarrow Cu^{2+}$

**(11) BORON**

- absorbed as → $BO_3^{3-}$, $B_4O_7^{2-}$
- req. for (1) uptake & (2) utilisation of → $Ca^{2+}$
- → carbohydrate translocation
- Pollen germination
- membrane functioning
- Cell differentiation
- Cell elongation

**(12) MOLYBDENUM**

- obtained as → $MoO_2^{2+}$ (molybdate ions)
- component of several enzymes → Nitrogenase, Nitrate Reductase
- both participate in Nitrogen metabolism

**(13) CHLORINE**

- obtained as → $Cl^-$
- $Na^+$, $K^+$ & $Cl^-$ → determines solute conc. → anion - cation balance in cells
- essential for water splitting rkn in photosynthesis
- rkn leads to → $O_2$ evolution

# Deficiency Symptoms Of Essential Elements

When supply of an essential element → becomes limited → plant growth retarded

Concentration below which plant growth is retarded → Critical Concentration

* Since, each element —has→ one or more specific → structural role / → functional role ] hence

absence of any element (particular) —plants shows→ certain morphological changes.

these are indicative of → certain element deficiency —called as→ "Deficiency Symptoms"

→ vary from element to element

& these symptoms disappear as → deficient mineral is provided to plant.

But if → deprivation continues —it may eventually lead to→ death of the plant.

* Elements that are actively mobilized within plants —exported to→ young developing tissue → deficiency symptoms first appear in older tissues (senescent leaves).

N, K, Mg

* (In older leaves) — biomolecules containing these comp break down making these elements available for mobilizing to younger leaves.

* Elements that are immobile (not transported out of the mature organ) → deficiency symptoms first appear in young tissues

S, Ca → part of structural component of the cell. hence are not released easily.

* This aspect of mineral nutrition of plants —is of great significance / importance to→ Agriculture, → Horticulture

* Kind of deficiency symptoms —in plants include→ Chlorosis, → Necrosis, → stunted plant growth, → premature fall of leaves & buds, → Inhibition of cell division

* Chlorosis → loss of chlorophyll —leading to→ yellowing of leaves.

* Necrosis → Death of tissue (particularly leaf tissue)

Chloresis → N K Mg S Fe Mn Zn Mo

Necrosis → Ca Mg Cu K

Inhibition of cell division → N K S Mo

Delay in flowering → N S Mo

* Defeciency of any element can cause multiple symptoms
* And same symptomps may be caused by defeciency of sequence different elements
* Different plants respond differently to deficiency of same element.

## TOXICITY OF Micronutrients

* Requirement of micronutrients is always low
* Their moderate ↓↓ → deficiency symptoms
* Their moderate ↑↑ → Toxicity

There is a "narrow range of concentration" at which the elements are optimum

* Any mineral ion concentration in tissue that reduces → dry weight of tissues by about 10% is TOXIC CONC.

* Such critical conc → vary widely among different micronutrients
* Toxicity symptoms → difficult to identify
* Toxicity levels for any element also vary for different plants

* Many times excess of an element may inhibit uptake of another element.

EXAMPLE

Prominent symptoms of manganese toxicity is → Brown spots surrounded by chlorotic veins.

Mn competes with → Fe, Mg for → uptake

specifically with Mg → binding with enzymes.

Mn inhibits → Ca translocation in shoot apex.

* Excess of Mn may cause deficiency of → Fe, Mg, Ca

Thus, symptoms of Toxicity of Mn ≈ Symptoms of deficiency of Fe, Mg, Ca



## MECHANISM OF ABSORPTION OF ELEMENTS

Much of the studies on mechanism of absorption of elements by plants has been carried out in Isolated → cells, tissues, organs.

process of absorption is demarcated into 2 main phases.

### First phase

* Initial rapid uptake of ions into → "free space" / "outer space" of cells (APOPLAST)
* ITS PASSIVE.
* Occurs through ION CHANNELS (the trans membrane proteins) function as selective pores.

### Second phase

* Ions moved to "inner space" (SYMPLAST of cells)
* Exit or entry of ions to & from symplast req. expenditure of metabolic energy. (ACTIVE PROCESS)

Movement of ions – FLUX.

Inward movement

↓

Influx

Outward movement

↓

Efflux.

# TRANSLOCATION OF SOLUTES

Mineral salts $\xrightarrow[\text{through}]{\text{are translocated}}$ Xylem (alongwith - ascending stream of water)

pulled up through plant by → Transpirational pull.

* Analysis of xylem sap → shows → presence of mineral salts.
* Use of radioisotope element minerals substantiate that they are transported through xylem.

# SOIL AS RESERVOIR OF ESSENTIAL ELEMENTS

Majority of elements → become → available to roots → by → Weathering / Breakdown of rocks

these processes → enrich the soil → with → dissolved → ions / inorganic salts.

Since, they are derived from → rock minerals $\xrightarrow{\text{their role in}}$ plant nutrition is refered as "mineral nutrition"

* Soil has wide variety of substance, its functions
  - supplies minerals
  - harbours $N_2$-fixing bacteria.
  - other microbes
  - holds water
  - supplies air to roots
  - Acts as a matrix that stabilize the plant.

* Since, defeciency of essential minerals - affects crop yeild → there's often a need to supply them through "fertilizers"!

$N, P, K, S$ ← Macro-nutrient

$Cu, Zn, Fe, Mn$ — Micro-nutrient

which contain both



# METABOLISM OF NITROGEN

## (1) NITROGEN CYCLE

Apart from C, H & O, "Nitrogen" is the most prevalent element in living org.

* Nitrogen $\xrightarrow[\text{ent of}]{\text{is a constitu}}$
  - AA
  - proteins
  - hormones
  - chlorophylls
  - vitamins

* Plants compete with microbes → for → limited Nitrogen available in soil.
* NITROGEN → is → limiting nutrient → for both
  - Natural ecosystem
  - Agricultural ecosystem.

exists as → strong triple covalent bond → $N \equiv N$.

## ⊙ NITROGEN FIXATION — $N_2 \longrightarrow NH_3$ (conversion)

In Nature
- Lightening
- UV radiations

provide enough energy → to convert nitrogen into nitrogen Oxides
- $NO$
- $NO_2$
- $N_2O$

Industrial combustion, Forest fires, Automobile exhaust, Power generating stations → source of atmospheric nitrogen oxides.

AMMONIFICATION – Decomposition of → organic nitrogen of → dead plants & animals into $NH_3$

* Some of this $NH_3$ → volatilises & re-enters the atmosphere
→ Most of it – converted into nitrate by soil bacteria.

① $2NH_3 + 3O_2 \xrightarrow{\text{oxidation}} 2NO_2^- \text{(nitrite)} + 2H^+ + 2H_2O$ → Nitrosomonas/Nitrococcus

② $2NO_2^- + O_2 \xrightarrow{\text{oxidation}} NO_3^- \text{(nitrate)}$ → Nitrobacter

CHEMOAUTOTROPHS

These steps are → NITRIFICATION.

Nitrate thus formed $\xrightarrow{\text{absorbed by}}$ plants and is transported to → leaves "reduced" to form → $NH_3$ $\xrightarrow{\text{that finally forms}}$ amine grp of AA.

$NO_3^- \xrightarrow[\text{Pseudomonas, Thiobacillus}]{\text{denitrification}} N_2$

## BIOLOGICAL NITROGEN FIXATION

- Very few living organisms $\xrightarrow{\text{can utilise}}$ Nitrogen in $N_2$ form (available abundantly in air)
- Only certain Prokaryotic species $\xrightarrow{\text{capable of}}$ fixing nitrogen

$\boxed{N_2 \xrightarrow[\text{living org.}]{\text{"Reduction" by}} NH_3}$ $\xrightarrow{\text{is}}$ BIOLOGICAL NITROGEN FIXATION

* Enzyme – NITROGENASE – capable of $N_2$ reduction is present exclusively in Prokaryotes
Such microbes → $N_2$ – fixers

$N \equiv N \xrightarrow{\text{nitrogenase}} NH_3$

N₂ fixing Bacteria

FREE LIVING

Anaerobic
① Rhodospirillum
② Clostridium

Aerobic
① Azotobacter
② Beijernickia
③ Bacillus → free living
④ cyanobacteria Anabena Nostoc

# Symbiotic Biological $N_2$ fixation

most prominent

★ Legume – Bacteria relationship

Species of ROD-SHAPED - Rhizobium

have relation with

several legumes

alfa alfa, sweet clover, sweet pea, lentils, Garden pea, Broad bean, clover bean

* most common association on roots is as nodules

small outgrowths on roots.

In NON-LEGUMINOUS PLANT (alnus)

Frankia → produce $N_2$ fixing nodules

* Both → Rhizobium, Frankia → Free living in soil → can fix $N_2$ atm. as "symbionts"

* Uprooting any common pulse before flowering → You'll see near, spherical outgrowths on the roots (NODULES)

central portion is Red/Pink due to the presence of

① "Leguminous haemoglobin"

OR

② "Leg-haemoglobin"

## NODULE FORMATION

→ involves a sequence of multiple interaction b/w Rhizobium and Roots of host plant

① Rhizobia multiply & colonize the surrounding of roots

↓

② It gets attached to • epidermal cells • Root hair cells

↓

③ Root hair curl & bact. invade root hair

↓

④ An infection thread is produced carrying bact. to cortex of the root, where they initiate

⑤ nodule formation in cortex of root.

↓

⑥ Bact. is then released from the thread into

↓

⑦ Cells, which leads to differentiation of specialised $N_2$ fixing cells.

↓

⑧ Nodule thus formed, establishes a direct vascular connection with HOST

↓ for

⑨ exchange of nutrients.

Nodule $\xrightarrow{\text{contains}}$ all the necessary biochemical components

Date
Page

Enzyme

NITROGENASE

① Mo-Fe protein
② Calalyze : atm $N_2 \rightarrow NH_3$

You always confuse it with $NO_3$

FIRST STABLE PRODUCT OF NITROGEN FIXATION

③ Highly sensitive to mol. $O_2$
④ Requires anaerobic cond.

Leg-haemaglobin

① Oxygen scavenger
② Protects the enzyme from oxygen.

Microbes $\xrightarrow{\text{live as}}$ aerobes (under free living conditions)
(NITROGENASE NOT FUNCTIONAL HERE)

during $N_2$ fixing
Become anaerobic
thus protecting nitrogenase enzyme

$$N_2 + 8e^- + 8H^+ + 16ATP \longrightarrow 2NH_3 + H_2 + 16ADP + 16P_i$$

requires very high input of energy
8 ATP for each $NH_3$.

Respiration of Host cells. ← this energy is obtained by

## FATE OF AMMONIA

* At physiological pH, $NH_3 \xrightarrow{\text{protonated}} NH_4^+$ (ammonium)
* Most of the plants $\xrightarrow{\text{can assimilate}}$ nitrate ($NO_3^-$) / ammonium ($NH_4^+$) → toxic to plants & hence cannot accumulate in them

$NH_4^+ \xrightarrow[\text{synthesize}]{\text{is used to}}$ AA in plants

2 ways.



### Reductive amination

$\alpha$-Ketoglutaric acid + $NH_4^+$ + NADPH
↓ Glutamate Dehydrogenase
glutamate + $H_2O$ + NADP

### Transamination

Transfer of amino group from one AA → to Keto grp of Keto acid

* Glutamic acid is main AA from which transfer of $NH_2$ (amino grp) takes place.
* Other AA $\xrightarrow[\text{through}]{\text{formed}}$ transamination
* Enzyme — Transaminase

$$R_1-\underset{NH_3^+}{\overset{H}{C}}-COO^- + R_2-\underset{\|O}{C}-COO^- \rightleftharpoons R_1-\underset{\|O}{C}-COO^- + R_2-\underset{NH_3^+}{\overset{H}{C}}-COO^-$$

Amino-donor    amino-acceptor

Two most important amides – ① Asparagine ② Glutamine → found in plants → are structural part of proteins

Asparagine $\xrightarrow[\text{by}]{\text{formed}}$ Asparatic acid + amino grp

Glutamine $\xrightarrow{''}$ Glutamic acid + amino grp

(–OH grp of acid $\xrightarrow[\text{by}]{\text{replaced}}$ another $NH_2^-$ radical)

Since, Nitrogen content: Amides > Amino acids → they are transported to other parts of plant via Xylem vessels.



* In addition, along with transpiration stream + nodules of some plants (eg- Soyabean) – export fixed $N_2$ as ureides → have "high $\frac{N}{C}$ ratio"

* Plants obtain inorganic nutrients from → air, water, soil

* Out of 105 elements → 17 – essential elements, → 4 – Beneficial elements ] Total - 21

* Elements are constituents of → carbohydrate, fats, nucleic acid, proteins; → Various metabolic processes.

* $N_2$ fixation $\xrightarrow{\text{requires}}$ Energy in form of ATP, strong reducing agents. ($H^+$)

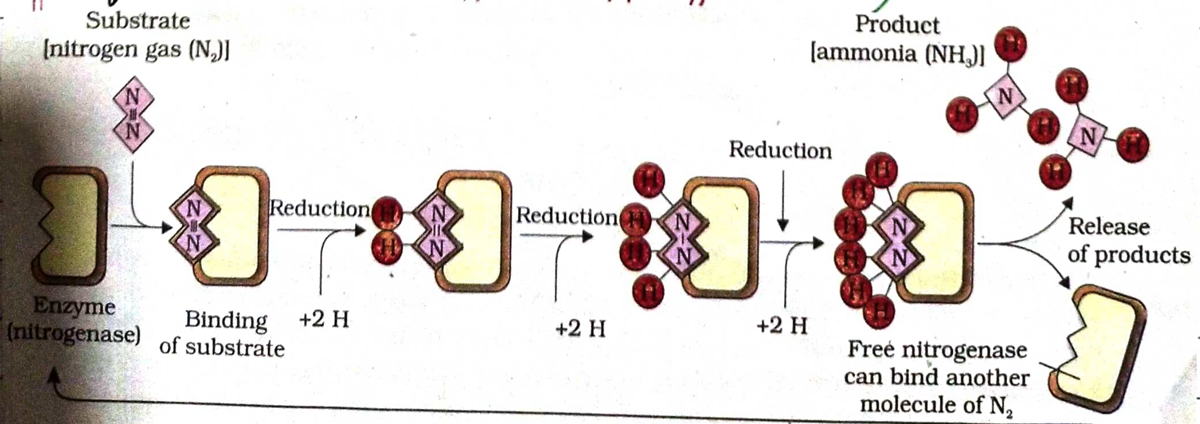


**Figure 12.5** Steps of conversion of atmospheric nitrogen to ammonia by nitrogenase enzyme complex found in nitrogen-fixing bacteria

Boron deficiency leads to Stout axis

Every mineral element that is present in a cell is not needed by cell

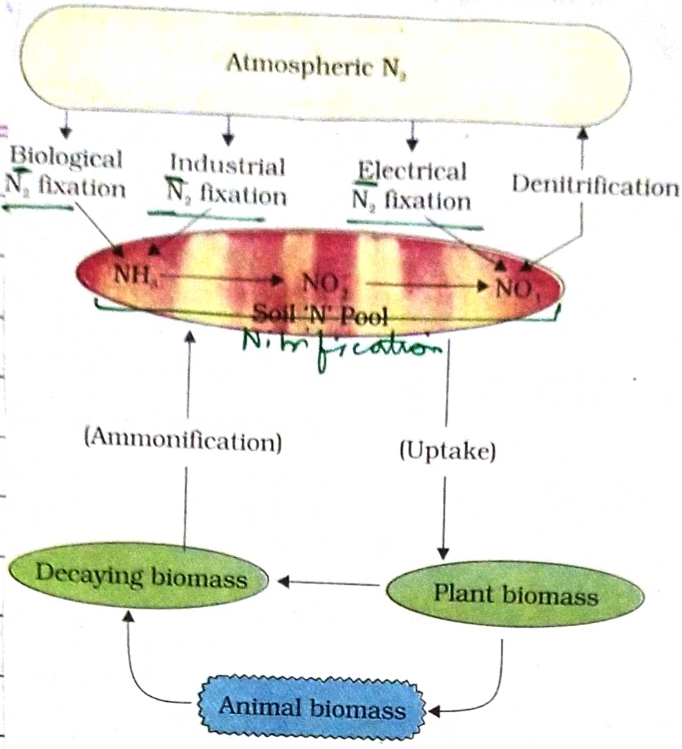


**Figure 12.3** The nitrogen cycle showing relationship between the three main nitrogen pools – (1) atmospheric (2) soil, and (3) biomass

Nitrogen is highly mobile

It's very challenging to establish essentiality of micronutrients bcz they are req. only in trace quantities

* $N_2$ → very essential for sustenance of life

* Most of nitrogen fixation in nodule takes place in anaerobic environment.

* $NH_3$ (prod. by $N_2$ fix.) $\xrightarrow[\text{into}]{\text{is incorporated}}$ AA as the amino grp

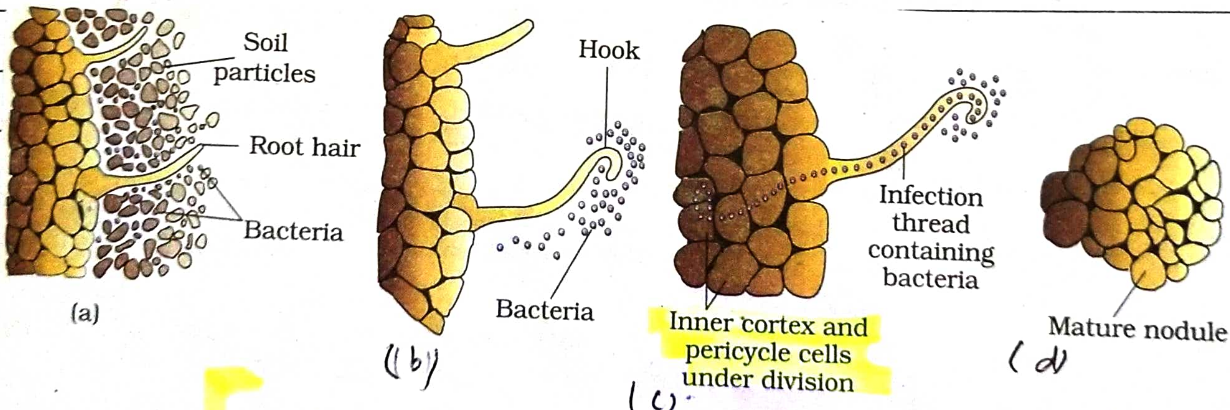


**Figure 12.4** Development of root nodules in soyabean : (a) *Rhizobium* bacteria contact a susceptible root hair, divide near it, (b) Successful infection of the root hair causes it to curl, (c) Infected thread carries the bacteria to the inner cortex. The bacteria get modified into rod-shaped $\boxed{\text{bacteroids}}$ and cause inner cortical and pericycle cells to divide. Division and growth of cortical and pericycle cells lead to nodule formation, (d) A mature nodule is complete with vascular tissues continuous with those of the root

Imp